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TECHNICAL REPORT 33

EPOXY AND GALVANIZED REINFORCEMENT BARS IN MONOLITHIC CONCRETE BRIDGE DECKS: IN-SERVICE EVALUATION

SECOND INTERIM REPORT
JUNE, 1979

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EPOXY AND GALVANIZED REINFORCEMENT BARS IN MONOLITHIC CONCRETE BRIDGE DECKS: - IN-SERVICE EVALUATION

2nd INTERIM REPORT

Conducted in Conjunction With
The U.S. Department of Transportation
Federal Highway Administration
National Experimental and Evaluation Program (NEEP) No. 16
Coated Reinforcing Steel for Bridge Decks

prepared by

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(Technical Report 33)

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ABSTRACT

The purpose of this study is to evaluate the in-service performance of epoxy coated and galvanized reinforcing steel. These coatings are being investigated as a method of delaying the corrosion of reinforcing bars in concrete bridge decks. To evaluate the performance of coated bars, these materials and uncoated reinforcing bars have been used in the new construction of monolithic concrete bridge decks at two test sites.

This report compares the performance of the reinforcing bars after three years in service at one test site. At the second location the performance of the coated bars is reported on after one winter; the uncoated reinforcing at this second area has been in service for 2-3/4 years.

After three years at the Arcade Test Site all bar types are performing satisfactorily. Hairline surface cracks have developed on one of the two spans with galvanized reinforcing and on each of the spans constructed with epoxy and uncoated bars. Depth of steel measurements have shown that the thickness of concrete cover over each crack is less than two (2") inches. The average corrosion potential on the two spans with galvanized reinforcing was recorded at 0.29v. and 0.30v. in the latest survey; the epoxy coated bars show an average potential of 0.19v. and the uncoated reinforcing, a potential of 0.15v.

At the Interstate Route 88 Test Site all bar types are considered satisfactory, however, corrosion potential measurements indicate that some active corrosion of the epoxy coated reinforcing is occurring. In the latest survey the average corrosion potential on the two bridges with galvanized reinforcing was 0.33v. and 0.37v. The two bridges with epoxy bars had average potentials of 0.32v. and 0.29v., but on one structure 42% of the individual measurements exceeded the 0.35v. threshold for actively corroding bars. The one bridge with uncoated reinforcing had an average potential of 0.19v. No cracks or other defects were evident on any of the test bridges at this location.

A review of the contract costs for 22 bridges that were constructed with uncoated and epoxy coated reinforcing bars in 1977, shows that New York is paying 22½ cents/lb. more for epoxy coated bars.

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I. INTRODUCTION

Background

The corrosion of reinforcing steel due to the penetration of de-icing salts has been identified as a major contributing factor in the early deterioration of concrete bridge decks. Monolithic concrete bridge decks are permeable. Chloride ions from de-icing salts migrate through the concrete and in their presence the corrosion of unprotected steel reinforcement proceeds at an accelerated rate. The corrosion product (rust) that is formed is 5 to 10 times as voluminous as the original material. This increased volume of the reinforcing bar creates tensile stresses within the concrete which eventually result in cracking, spalling and deterioration of the bridge deck.

To eliminate this problem, several methods have been proposed to prevent corrosion in concrete decks. These include coating reinforcing bars; increasing the thickness of concrete cover; cathodic protection; waterproofing membranes; and less permeable wearing courses (e.g. latex modified, high density, low slump; polymer concretes, etc.) For monolithic bridge deck construction, New York believes that coating reinforcing bars is the most practical method for reducing corrosion at the present time.

Purpose and Scope

This study is being conducted in conjunction with National Experimental Evaluation Program (NEEP) No. 16, Coated Reinforcing Steel for Bridge Decks. The primary objective of the program is to evaluate the in-service performance of epoxy coated and galvanized reinforcing steel. These coatings are being investigated as a method of delaying the corrosion of reinforcing bars in new monolithic concrete bridge decks. The evaluation is being made by comparison of the coated bars with uncoated reinforcing that has been used in the construction of the same type of decks.

This report compares the performance of the reinforcing bars after three years in service at one test site. At a second location the performance of the coated bars are reported after one winter.

Previous Work

This study was initiated in 1975. To evaluate the epoxy coated and galvanized reinforcing, these materials and uncoated bars have been used in the new construction of 8" thick, monolithic concrete bridge decks. In this design the nominal concrete cover over the top mat of reinforcing is two (2") inches. Figure 1 shows a transverse section of the eight-inch monolithic deck.

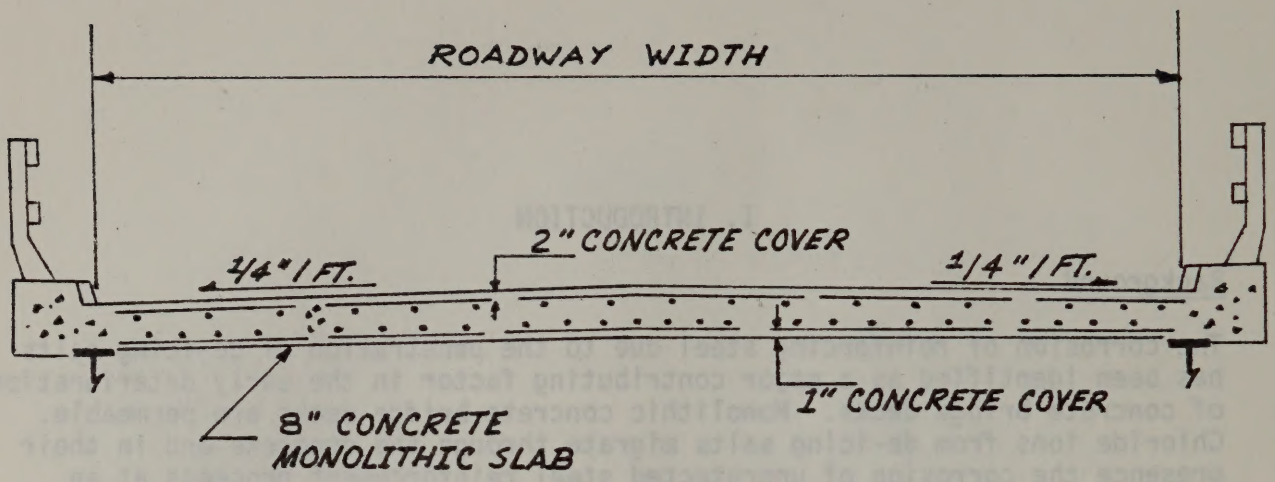


Figure 1 Typical Transverse Section: 8" - Monolithic Concrete Bridge Deck

Test Structures were built under separate construction contracts and are located on N.Y. Route 39 in Arcade, N.Y.; and on a section of Interstate Route 88, north of Binghamton, N.Y. For the purpose of taking electrical measurements, each test structure has been instrumented. The instrumentation consists of a wired ground connection to each of 4 longitudinal and 4 transverse reinforcing bars in the top mat; and moisture-temperature sensing devices that are embedded in the concrete at the top level of steel reinforcing. The connections and sensing devices are terminated in a junction box and are available for use in each evaluation.

The test structure in Arcade, N.Y. (Arcade Test Site) was constructed in August, 1975, and the bridge was opened to traffic in October, 1975. This bridge consists of four (4) simple spans. Two of the spans are constructed with galvanized reinforcing; one span with epoxy coated reinforcing; and one span contains uncoated reinforcing bars.

The test area on Interstate Route 88 (I-88 Test Site) includes five bridges that are being evaluated in this study. Two of these structures are single spans, constructed with epoxy coated reinforcing; another two are also single span bridges, but constructed with galvanized reinforcing bars. The fifth bridge is a 4-span, continuous structure that has been constructed with uncoated reinforcing bars. Only one of the 4 spans on this bridge is being observed.

At the I-88 Test Site the two bridges with epoxy coated bars were built in August, 1976; and the two with galvanized bars in October, 1976. These four structures were not put in service until December, 1977. The one structure with uncoated reinforcing was constructed in conjunction with an earlier contract in June, 1975, and was opened to traffic in September, 1975.

Table 1 summarizes the test structures and the number of performance evaluations made to the present time. Four evaluations have been made at the Arcade Test Site; the first immediately before the bridge was opened to

traffic and the remaining surveys at yearly intervals. Only two evaluations have been completed at the Interstate Route 88 Test Site. On Bridges 1 and 9, with the coated bars, the first survey was made before the structures were placed in service and the collected data is representative of new and unsalted bridge decks. Bridge 11 with the uncoated reinforcing was built on an earlier contract and the data from the initial survey (5/77) is representative of a deck which had been in service at that time for approximately 1-3/4 years, including two winter seasons.

The first interim report on this evaluation was published in February, 1977 (Technical Report 31, Epoxy and Galvanized Reinforcement Bars in Monolithic Concrete Bridge Decks: In-Service Evaluation). This initial reporting provided a detailed description of the test sites; materials and contract specifications; initial cost information; observations of the construction process; and the results of the first two evaluations at the Arcade Test Site. To familiarize the reader, a summary of that report is re-printed below; and a description of the materials used in the construction of the experimental decks is abstracted in Appendix A.

SUMMARY (Re-printed from Technical Report 31, dated February, 1977)

"No problems were encountered in the shop coating and fabrication, or with the job site installation of epoxy coated and galvanized reinforcing bars. Epoxy coated bars were not severely damaged in shipment or handling and only minor field touch-up was necessary. No field repair of the galvanized reinforcing bars was needed.

The initial evaluation of the reinforcing bars that have been installed at the Interstate Route 88 test site, will be performed in Spring, 1977. The concrete bridge deck work on the structures with epoxy coated and galvanized reinforcing steel was not completed until October, 1976, and early winter weather has prevented the post-construction survey. These structures will not be opened to traffic until the latter part of 1977.

Two performance evaluations have been made at the Arcade test site; the first in 1975, before the bridge was opened to traffic and the second in 1976, after one year of service and one winter season. After one year of service all bar types are performing satisfactorily. There are no indications of active corrosion; and the chloride content at the level of the steel reinforcement is not suffcient to promote active corrosion (<1.3 lb. Cl-/c.y.).

The corrosion potential data indicates that the galvanized reinforcement bars have passivated; from approximately 0.3±v. in 1975 to 0.22± v. in 1976. The corrosion potential measurements on epoxy coated bars have remained about the same in each evaluation (0.12-0.13 v.). The uncoated reinforcing bars have also remained stable, with a corrosion potential of about 0.10 v. in each survey."

TABLE 1 - TEST STRUCTURES AND PERFORMANCE EVALUATIONS

Test Structure	Bar Type	Date of Construction	Date In-Service	Dates of Performance Evaluations #1	#2	#3	#4	#5	#6
ARCADE TEST SITE									
Span No. 1	Galvanized	Aug., 1975	Oct., 1975	10/75	10/76	10/77	9/78		
Span No. 2	Galvanized	Aug., 1975	Oct., 1975	10/75	10/76	10/77	9/78		
Span No. 3	Epoxy	Aug., 1975	Oct., 1975	10/75	10/76	10/77	9/78		
Span No. 4	Uncoated	Aug., 1975	Oct., 1975	10/75	10/76	10/77	9/78		
I-88 TEST SITE									
Bridge 1 - Eastbound	Epoxy	Aug., 1976	Dec., 1977	5/77	5/78				
Bridge 1 - Westbound	Epoxy	Aug., 1976	Dec., 1977	5/77	5/78				
Bridge 9 - Eastbound	Galvanized	Oct., 1976	Dec., 1977	5/77	5/78				
Bridge 9 - Westbound	Galvanized	Oct., 1976	Dec., 1977	5/77	5/78				
Bridge 11 - Westbound	Uncoated	June, 1975	Sept., 1975	5/77	5/78				

II. METHODS OF EVALUATION

The in-service performance of epoxy coated, galvanized and uncoated reinforcing bars is being evaluated on the basis of annual surveys. In each survey, the following observations and measurements are made:

1. Visual Observations: - to locate cracks,spalls, areas of scaling and other types of distress.

2. Delaminations: - a chain drag is used to detect delaminated areas. Delaminations are usually caused by corrosion of the reinforcing bars. The end result of these defects are spalls.

3. Pachometer Survey: - a "depth of steel" survey is made with a pachometer to determine the thickness of concrete cover over the top mat of reinforcing steel. This survey is performed on a 5' coordinate grid and done only once, after the concrete deck is placed.

4. Chloride Content: - chloride samples are collected from nominal depths of 1", 2" and 3" (samples taken from 3/4 to 1-1/4"; 1-3/4 to 2-1/4"; and 2-3/4 to 3-1/4"). Research by others has shown that a chloride content of 1.0 to 1.3 pounds of free chloride per cubic yard of concrete is sufficient to promote active corrosion of the uncoated reinforcing bars.

5. Corrosion Potential: - corrosion potential surveys are made on a 5' coordinate grid using a copper-copper sulphate half-cell reference electrode. Research with uncoated reinforcing has shown that for half-cell values (CSE) less than 0.20 v., active corrosion is not occurring; and that for values above 0.35 v., active corrosion is occurring. The range of values between 0.20 v. and 0.35 v. represents an area where corrosion activity is undefined.

It should be noted that the values above represent the negative potential of the steel relative to the copper-copper sulphate half cell, e.g. 0.20 v. represents an actual corrosion potential value of -0.20 v. For purposes of this report the negative sign is dropped and a value such as -0.27 v. is recorded as 0.27v.

The interpretation of corrosion potential values for epoxy coated and galvanized reinforcing has not been defined. Since epoxies are inert and do not react (corrode), the measured half-cell values can be attributed to coating defects and corrosion of the unprotected bar. The values that have been established for uncoated reinforcing should apply to epoxy coated bars; however, in interpreting the data it must be considered that a high corrosion potential value could be due to localized pinpoints of rust or other factors, and not a general deterioration of the epoxy coating system. Galvanized

coatings are sacrificial and corrosion potential measurements for galvanized bars will reflect the corrosion potential of the zinc. The corrosion potential of actively corroding zinc in concrete bridge decks is not known, however, it is expected to be above 0.60 v. (CSE). No interpretation of the corrosion potential measurements on galvanized reinforcing bars will be made at the present time.

III OBSERVATIONS AND MEASUREMENTS

1. Visual Observations:

a. Arcade Test Site

After three years of service, surface cracks are visible on one of the two spans with galvanized bars and on each of the spans with epoxy coated and uncoated reinforcing. Figure 2 is a plot of the surface cracking on the Arcade bridge. All of the defects are "fine" cracks with no measureable gap between adjoining faces. In an attempt to determine a cause for the cracking the depth of concrete cover over each crack was measured with a pachometer. In all cases the concrete cover was measured as less than two inches.

b. I-88 Test Site

No visual defects were noted on any of the test structures at this location.

2. Delaminations:

At both the Arcade and I-88 locations a chain drag on the surface of each bridge has shown no evidence of delamination for any of the bar types.

3. Pachometer Survey:

The depth of steel survey was performed at each test site in the first survey year. Measurements were recorded on a 5'-coordinate grid spacing. The results of the pachometer surveys are summarized in Table 2. All of the test bridges showed an average concrete cover in excess of two (2") inches.

4. Chloride Content:

In each annual evaluation chloride samples have been collected from four (4) random locations for each bar type. At Arcade the samples are taken at the rate of 4/span and at I-88, 4/structure. Table 3, Summary of Performance Data, gives the average chloride content of the four locations, at each sample depth, for each of the test locations.

Examination of Table 3 shows that at Arcade, the chloride content at the level of steel reinforcing (2" depth) on all spans is now sufficient to create an environment for active corrosion to occur (1-1.3 lbs. Cl^-/c.y.). At the I-88 Test Site, the contamination at the two (2") inch sample depth is negligible and below the threshold limit.

TABLE 2 - PACHOMETER SURVEY

Test Site/Reinforcing	Mean Depth Conc. Cover (inches)	Std. Dev. (in.)	Min. (in.)	Max. (in.)	No. Meas. (n)
1. ARCADE TEST SITE					
Span 1 - Galvanized	2.630	0.268	2.25	3.00	81
Span 2 - Galvanized	2.224	0.382	1.50	3.00	172
Span 3 - Epoxy	2.157	0.352	1.25	3.00	169
Span 4 - Uncoated	2.300	0.256	1.75	3.00	125
2. I-88 TEST SITE					
Bridge 9 EB - Galvanized	2.359	0.432	1.25	3.50	253
Bridge 9 WB - Galvanized	2.261	0.367	1.25	3.50	264
Bridge 1 EB - Epoxy	2.788	0.236	2.00	3.50	234
Bridge 1 WB - Epoxy	2.856	0.328	1.75	3.75	234
Bridge 11 WB - Uncoated	2.570	0.502	1.50	3.75	136

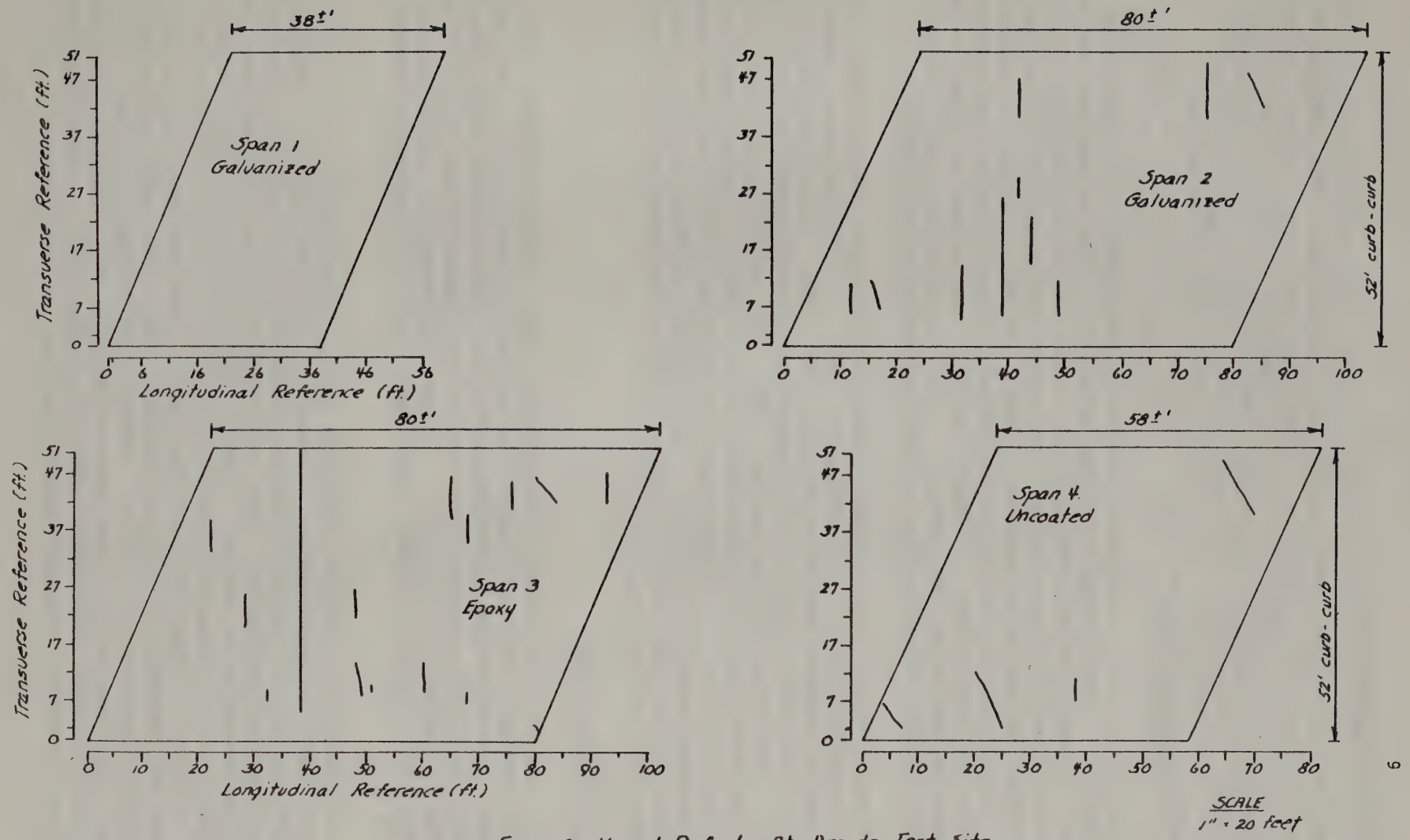


Figure 2 - Visual Defects At Arcade Test Site

5. Corrosion Potential:

The results of the corrosion potential measurements for each year's survey are included in Table 3. In addition for clarity Figures 3 and 4 are bar charts that visually display the percentile of data values within the corrosion intervals of less than 0.20 v.; 0.20-0.35 v.; and greater than 0.35 v. for each year the reinforcing bars have been in service.

a. Arcade Test Site

After three years in service, all bar types appear to be performing satisfactorily. The average corrosion potential of the galvanized bars on Spans 1 and 2 was recorded as 0.29 v. and 0.30 v. respectively in 1978. These values are approximately the same as the measurements that were recorded before the bridge was placed in service in 1975. The passivation of the galvanized coating that occurred in the following two surveys appears to have ended. Although the 1978 evaluation indicates increased corrosion activity, the potential level is below the 0.60 v. threshold that has been estimated for actively corroding galvanized bars.

The epoxy coated and uncoated reinforcing bars have shown slight increases in corrosion activity in each survey year. In 1978 the epoxy coated bars showed an average corrosion potential of 0.19 v. While this average indicates inactive corrosion, the percentage of measurements in the less than .20 v. corrosion interval was only 50%. The remaining 50% of the data values were recorded in the 0.20-0.35 v. interval (1 measurement was taken at 0.36 v.). By comparison the uncoated reinforcing bars showed an average potential of 0.15 v. in 1978; 92% of the data points were recorded as less than 0.20 v., and only 8% in the undefined 0.20-0.35 v. corrosion activity interval.

b. I-88 Test Site

After 1/2 year in service the galvanized bars are satisfactory. The initial average corrosion potential on Bridge 9 EB was 0.29 v.; the second annual survey that was performed after the structure had been opened to traffic for 1/2 year and after one winter's season showed a slight increase in potential to 0.33 v. Bridge 9 WB showed an initial average potential of 0.38 v.; after a half year's use this average decreased to 0.37 v.

On the basis of corrosion potential data, the performance of the epoxy coated bars is questionable. Although it is highly doubtful that serious deterioration of the epoxy coating system has occurred in the short time that the bars have been in use, the potential data indicates that some active corrosion is present. The initial survey of Bridge 1, EB and WB showed average corrosion potentials of 0.27 v. and 0.29 v. respectively. In 1978 the average potentials for these structures were 0.32 v. and 0.29 v. These measurements of average potential are in the undefined corrosion interval, between 0.20-0.35 v. However, for Bridge 1, EB, only 47% of the actual data point values were recorded in this undefined interval while 42% of the individual readings exceeded 0.35 v., which indicates active corrosion. The westbound structure is slightly more passive with

75% of the individual data values recorded in the 0.20-0.35 v. interval and 14% measured at greater than 0.35 v.

The uncoated reinforcing bars on Bridge 11 WB showed an initial average corrosion potential of 0.20 v and a potential of 0.19 v. in 1978 when the deck had been in service for 2-3/4 years. In the latter survey, 56% of the measurements were in the inactive corrosion interval and 44% in the undefined 0.20-0.35 v. interval. The uncoated bars are considered satisfactory after 2-3/4 years at this test site.

TABLE 3 - SUMMARY OF REINFORCING BAR PERFORMANCE DATA

TEST SITE/REINFORCING	SURVEY YEAR	YEARS IN SERVICE	CONCRETE COVER - MEAN DEPTH	MEAN CHLORIDE CONTENT (lbs. Cl^-/c.y.) DEPTH 1"	2"	3"	CORROSION POTENTIAL NO. MEAS. (n)	MEAN (VOLTS)	STD. DEV. (VOLTS)	MIN. (VOLTS)	MAX. (VOLTS)	PERCENTILES < .20v.	.20-.35v.	> .35v.
1. ARCADE TEST SITE														
Span 1 - Galvanized	1975	0	2.6 in.	0.6	0.7	0.7	81	0.30	0.04	0.17	0.39	1	90	9
	1976	1		2.0	0.5	0.3	84	0.23	0.04	0.11	0.31	18	81	1
	1977	2		3.3	1.0	0.7	82	0.24	0.05	0.11	0.41	11	87	2
	1978	3		5.2	1.5	2.0	83	0.29	0.03	0.20	0.34	0	100	0
Span 2 - Galvanized	1975	0	2.2 in.	0.6	0.7	0.7	171	0.31	0.07	0.14	0.50	5	66	29
	1976	1		1.5	0	0	181	0.21	0.06	0.01	0.36	36	63	1
	1977	2		1.3	0.5	0.2	178	0.22	0.06	0.10	0.41	29	69	2
	1978	3		3.4	1.5	1.1	179	0.30	0.06	0.16	0.50	3	85	12
Span 3 - Epoxy	1975	0	2.2 in.	0.7	0.5	0.6	177	0.12	0.03	0.02	0.20	97	3	0
	1976	1		1.4	0.3	0	180	0.13	0.05	0.02	0.29	89	11	0
	1977	2		2.8	1.8	1.6	179	0.17	0.06	0.04	0.40	74	24	2
	1978	3		2.0	1.1	0.7	179	0.19	0.05	0.06	0.36	50	50	< 1
Span 4 - Uncoated	1975	0	2.3 in.	0.5	0.1	0.3	125	0.10	0.02	0.06	0.20	99	1	0
	1976	1		0.7	0	0	128	0.10	0.04	0.01	0.24	98	2	0
	1977	2		2.5	1.2	1.1	128	0.13	0.04	0.02	0.34	94	6	0
	1978	3		3.0	1.0	0.8	127	0.15	0.04	0.00	0.24	92	8	0
2. I-88 TEST SITE														
Bridge 9 EB-Galvanized	1977	0	2.4 in.	0.6	0.5	0.4	269	0.29	0.04	0.14	0.47	0	96	4
	1978	1/2		0	0	0	272	0.33	0.06	0.19	0.45	1	54	45
Bridge 9 WB-Galvanized	1977	0	2.3 in.	0.6	0.5	0.4	261	0.38	0.07	0.23	0.56	0	38	62
	1978	1/2		0	0	0	273	0.37	0.06	0.21	0.49	0	37	63
Bridge 1 EB-Epoxy	1977	0	2.8 in.	0.4	0.4	0.3	234	0.27	0.05	0.14	0.36	11	88	1
	1978	1/2		0.2	0	0	234	0.32	0.08	0.13	0.45	11	47	42
Bridge 1 WB-Epoxy	1977	0	2.9 in.	0.5	0.4	0.4	234	0.29	0.05	0.17	0.43	3	90	7
	1978	1/2		0.8	0.4	0.4	234	0.29	0.06	0.14	0.40	11	75	14
Bridge 1 WB-Uncoated	1977	1-3/4	2.6 in.	1.0	0.4	0.3	136	0.20	0.05	0.08	0.32	37	63	0
	1978	2-3/4		1.6	0	0	136	0.19	0.04	0.08	0.34	56	44	0

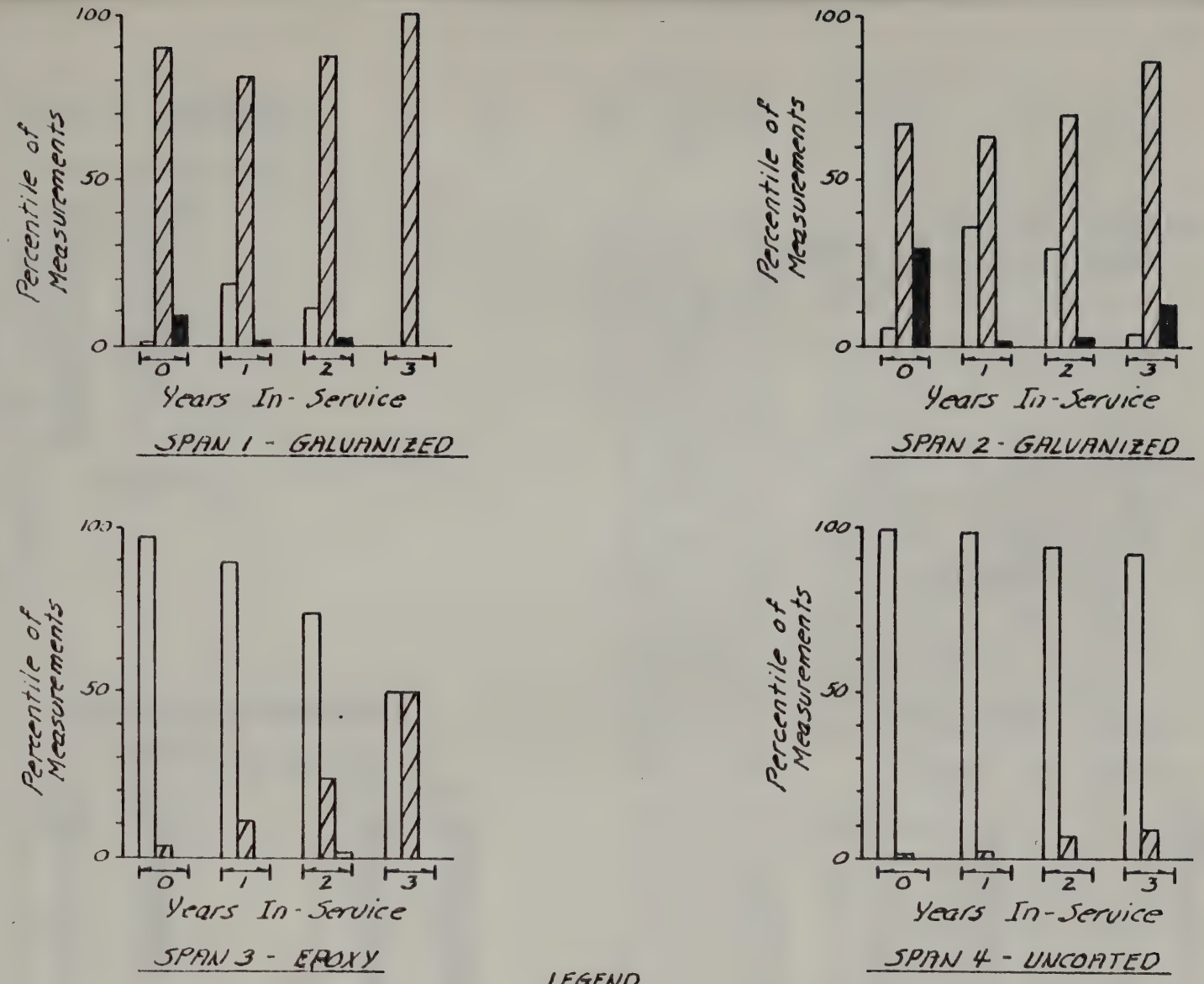
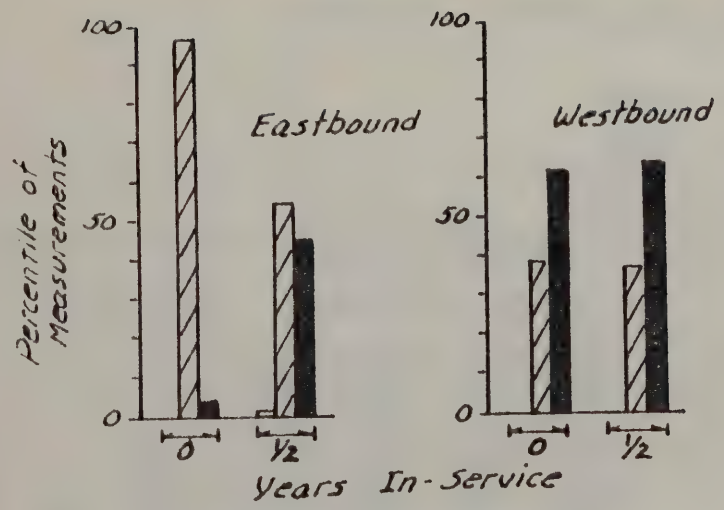
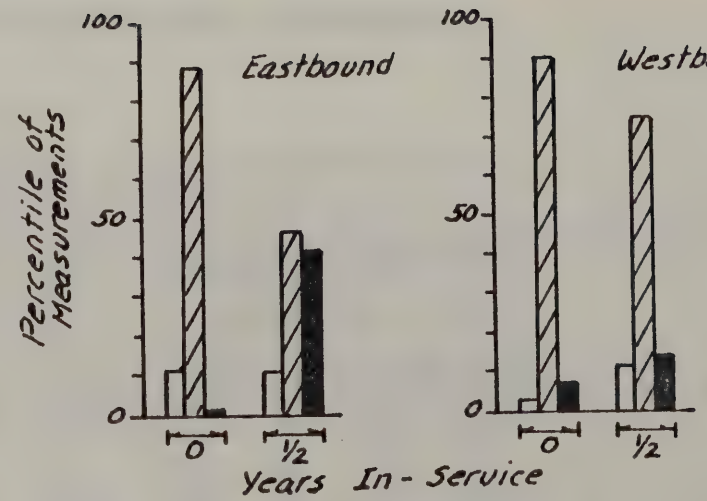


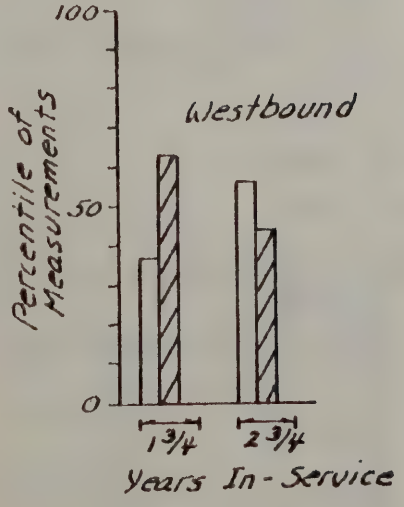
Figure 3 - Arcade Test Site : Corrosion Potential Measurements



BRIDGE 9 - GALVANIZED



BRIDGE 1 - EPOXY



BRIDGE 11 - UNCOATED

LEGEND

- — less than 0.20 V.
- — 0.20 to 0.35 V.
- — greater than 0.35 V.

Figure 4 - I-88 Test Site: Corrosion Potential Measurements

IV COST ANALYSIS

A cost analysis in terms of time-to-corrosion of the reinforcing bars is not possible at the present time. To provide some information, Table 4 summarizes the installed costs of the reinforcing bars at the test sites; and New York's contract installation costs for uncoated and epoxy coated reinforcing bars for the 1977 construction season (Jan. 1-Dec. 31). The contract installation costs are a result of new design standards for monolithic concrete bridge decks. These were adopted by the Department in October, 1976, for the purpose of controlling corrosion. Under these standards, our monolithic bridge decks are now constructed using epoxy coated bars in the top mat of steel reinforcing, while uncoated bars are used in the bottom mat. On the basis of recommendations by the Federal Highway Administration (FHWA), galvanized bars are not being used in New York at the present time. The future use of galvanized reinforcement will pend the results of this study.

Table 4 shows the bar costs for 22 bridges that were contracted in 1977. Each individual structure required both uncoated and epoxy coated bar reinforcing. The greater quantities of uncoated steel is due to its use in piers, abutments, etc., while the epoxy bars are normally located only in the top mat. Examination of Table 4, shows that the average cost for the epoxy reinforcing in New York, was approximately 22½ cents per lb. higher than for uncoated reinforcing steel.

TABLE 4 - REINFORCING BAR COSTS

1. TEST SITE INSTALLED COSTS

Bar Type	ARCADE TEST SITE		I-88 TEST SITE	
	Total Pounds	Cost ($/lb)	Total Pounds	Cost ($/lb)
Uncoated	32163	0.46	284680	0.23
Epoxy Coated	44729	1.34	504889	0.50
Galvanized	65768	0.79	430232	0.45

2. 1977 CONTRACT INSTALLED COSTS (UNCOATED & EPOXY COATED)

Contract Number	Bridge Identification Number	UNCOATED		EPOXY COATED		Cost Differential ($/lb)
		Total Pounds	Cost ($/lb)	Total Pounds	Cost ($/lb)	
D95486	1069840	14,800	0.50	10,225	0.70	0.20
D95487	Br. #8	121,370	0.42	20,630	0.63	0.21
	Br. #9	60,640	0.42	8,330	0.63	0.21
D95587	Br. 1A & 1B	107,260	0.33	57,112	0.55	0.22
	Br. 3A & 3B	809,997	0.33	500,731	0.55	0.22
	Br. 13	35,206	0.33	8,942	0.55	0.22
D95042	1031501	44,923	0.25	17,252	0.58	0.33
D95384	1023720	12,425	0.30	8,142	0.60	0.30
	1023710	17,474	0.30	13,640	0.60	0.30
D95368	1029820	36,839	0.30	24,102	0.50	0.20
D95497	1029840	31,422	0.37	8,003	0.60	0.23
	1029850	63,320	0.37	19,200	0.60	0.23
D95652	1040590	20,450	0.40	9,110	0.60	0.20
D95561	1014040	25,000	0.35	10,200	0.55	0.20
D95500	1026660	47,778	0.43	38,600	0.65	0.22
D95447	1003050	10,000	0.32	9,000	0.55	0.23
	3345500	24,100	0.35	28,443	0.55	0.20
D95445	1016870	39,000	0.35	38,000	0.57	0.22
D95372	1040910	30,450	0.30	25,150	0.50	0.20
D95418	1003170	46,825	0.39	32,200	0.55	0.16
D95246	0939	59,118	0.33	59,800	0.55	0.22
D95421	1027060	19,997	0.30	25,772	0.50	0.20
TOTAL POUNDS REINFORCING		1,678,394	--	972,584	--	--
AVERAGE COST PER LB			$0.35		$0.575	$0.224

V SUMMARY

Arcade Test Site

Four performance surveys have been made at the Arcade Test Site. At the time of the 1978 survey the bridge had been in service for three years including three winters. The chloride content at the level of steel reinforcing on all spans is sufficient to create a corrosive environment (greater than 1 lb. Cl^- /c.y.).

The galvanized reinforcing bars on Spans 1 and 2 show no evidence of active corrosion. The average corrosion potential on these two spans in the latest (1978) survey was recorded at 0.29 v. and 0.30 v. respectively. Span 1 shows no evidence of deterioration by other methods of evaluation. Some "hairline" cracks have developed on the surface of Span 2. Depth of steel measurements have shown that the concrete cover over each crack is less than two (2") inches.

The epoxy coated bars on Span 3 had an average corrosion potential of 0.19 v. in 1978. Fifty (50%) percent of the individual data measurements were recorded in the inactive (less than 0.20 v.) corrosion interval and the remaining measurements in the undefined 0.20-0.35 v. corrosion interval. Hairline cracks have also developed on the surface of Span 3; as with the galvanized bars the concrete cover over each crack has been measured at less than two (2") inches.

The uncoated reinforcing bars on Span 4 showed an average corrosion potential of 0.15 v. in the latest survey. Of this average, 92% of the data points were recorded as less than 0.20 v. and only 8% were in the undefined corrosion activity interval (0.20-0.35 v.). Several surface cracks are visible on the surface of Span 4; all are located where the concrete cover is less than two (2") inches.

Interstate Route 88 Test Site

Two performance surveys have been made at this test area. In the latest evaluation the bridges with the galvanized and epoxy coated bars had been in service for one-half year, including one winter. The bridge with the uncoated reinforcing had been in service for 2-3/4 years at the time of this survey. Chloride samples taken from each test bridge show that no structure has a chloride concentration at the level of steel reinforcing that is sufficient to promote active corrosion.

The two test bridges with galvanized reinforcing bars showed mean corrosion potentials of 0.33 v. and 0.37 v. in 1978. Active corrosion of the galvanized bars is not apparent. Other methods of evaluation show no defects on these structures.

The two bridges with epoxy coated reinforcing had corrosion potentials of 0.32 v. and 0.29 v. in the latest survey. These measurements of average potential are in the undefined 0.20-0.35 v. corrosion interval. Although it is highly doubtful that serious deterioration of the epoxy coating system has occurred in the short time that the bars have been in use, the potential survey does indicate that some active corrosion is present. No visual or other defects were evident on the bridges with epoxy bars.

The structure with uncoated reinforcing had an average corrosion potential of 0.19 v. in 1978, when the deck had been in service 2-3/4 years. Active corrosion of the bars is not indicated and other methods of evaluation show no defects.

Reinforcing Bar Cost

A review of the construction costs for 22 bridges that were contracted with uncoated and epoxy coated reinforcing bars in 1977 showed that New York paid an additional 22½ cents/lb. for the epoxy coated bars. No galvanized reinforcing was used in bridge construction projects during the 1977 construction season.

APPENDIX A

MATERIALS FOR MONOLITHIC BRIDGE DECK CONSTRUCTION

MATERIALS

Concrete for Monolithic Bridge Decks

The bridge decks in this evaluation were constructed using New York's standard Class A concrete mix design for structural slabs. Some general properties of this mix are as follows:

6.3 to 6.4 sacks of cement/cubic yard concrete
Water-Cement Ratio = 0.44
6% Air Entrainment
Maximum Aggregate size = 1-1/2 inch.

Reinforcing Bars

The steel reinforcing bars in this study (uncoated, epoxy coated and galvanized) conform to New York's standard requirements for deformed bars - ASTM A-615, Grade 60.

Galvanized (Zinc) Coating

Galvanized reinforcing bars were hot-dip galvanized in accordance with ASTM A-123. The average weight of zinc coating was specified at 2.3 oz/s.f. The slab zinc used in the coating process was specified to be equal to "Prime Western" grade (ASTM B-6). After galvanizing the bars were chromate treated.

Epoxy Coating

The reinforcing bars were coated with an electrostatically applied, powdered epoxy resin. The applied film thickness was specified at 7 $\pm$ 2 mils. In this study the reinforcing bars at both test sites were coated by the same applicator, (M.C.P. Facilities Corp. - Bath, Pa.) and with the same epoxy coating material (DuPont's Flintflex 531-6080).